APPENDIX J

AQUATIC DOSIMETRY AND HEALTH EFFECTS MODELS AND PARAMETER VALUES

J.1 Introduction

This appendix describes the methodology and the parametric values used to estimate dose equivalents and health risks for maximum and average individuals and for the population within the assessment area surrounding the generic underground uranium mine site in New Mexico and the generic surface mine site in Wyoming. In the appendix, the term dose quivalents refers to the following:

For radionuclides inhaled or ingested by an individual, dose equivalents are the annual committed dose equivalents that will be accumulated over 70 years following intake for an adult. For external exposure to an individual, dose equivalents are the annual dose equivalents to an adult for a radionuclide buildup time in the environment of 8.5 years (one-half the assumed period of mine operation of 17 years). For radionuclides inhaled or ingested by the population, dose equivalents are the annual collective dose equivalents that will be accumulated over 70 years following intake for an adult. For external exposure to a population, dose equivalents are the annual collective dose equivalents to an adult for a radionuclide buildup time in the environment of 8.5 years (one-half the assumed period of mine operation of 17 years).

Simple models are used throughout these calculations. The maximum individual calculations are performed independently from the population calculations. However, the average individual calculations are obtained by dividing the population calculations by the population size.

J.2 Pathways Considered

The aquatic pathway analyses consider the general surface stream flow pattern shown in Fig. J.1. The generic mine is dewatered by pumping water into the third order stream. Much of the year the only water flowing in the third order stream is mine water discharge. As the mine water travels downstream in the third order stream, it either percolates into the soil beneath the stream or evaporates. At some location downstream before the third order stream enters the second order stream, the third order stream dries up so that, for a large part of the year, the radioactive discharges in the mine water do not reach the second nor the first order streams. Some of the discharged radioactivity moves into the soil beneath the third order stream bed and the rest is probably deposited in the sediment on the stream bottom. The radioactivity deposited in the sediment is subject to resuspension and transport to the second order and first order streams during periods of flooding. However, during these floods, the resuspended radioactivity would be subject to the large dilution volumes associated with the flood. Some of the radioactivity that percolates into the soil could eventually reach shallow groundwater, but many of the radionuclides would be subject to large removal factors because of ion-exchange interactions between radionuclides and components of the soil. These interactions would cause groundwater concentrations of radionuclides to be greatly reduced when compared to the original surface water concentrations.

An effort has been made to use realistic computational methods and parametric data in these analyses whenever possible. However, when actual data did not exist, some conservative assumptions were made. The continuous stream flow assumption discussed in the following paragraph is the major conservative assumption in these aquatic analyses.

To correctly analyze the effects of radionuclides discharged from the mine to third order streams, one would have to have extensive hydrologic information on stream flow rates over a long period of record in order to predict the quantities of radionuclides reaching the second order and first order streams. One would also need extensive information on soil types and ion-exchange characterisitics of the soils within the stream bed areas. Because these data are not obtainable for use in these analyses, the simplifying assumption is made that the third order stream discharges mine water continuously into the second order stream and that the second order stream discharges continuously into the first order stream. Thus, the water concentrations of radionuclides in the first order stream are computed by dividing the annual radionuclide discharge from one mine by the average-annual flow rate in the first order stream. Population and average individual dose equivalents and health effects estimates are calculated using these water concentrations. Maximum individual dose equivalents and health effects are computed using the water concentrations in the second order stream which are computed by dividing the annual radionuclide discharges from one mine by the annual average flow rate for the second order stream. These

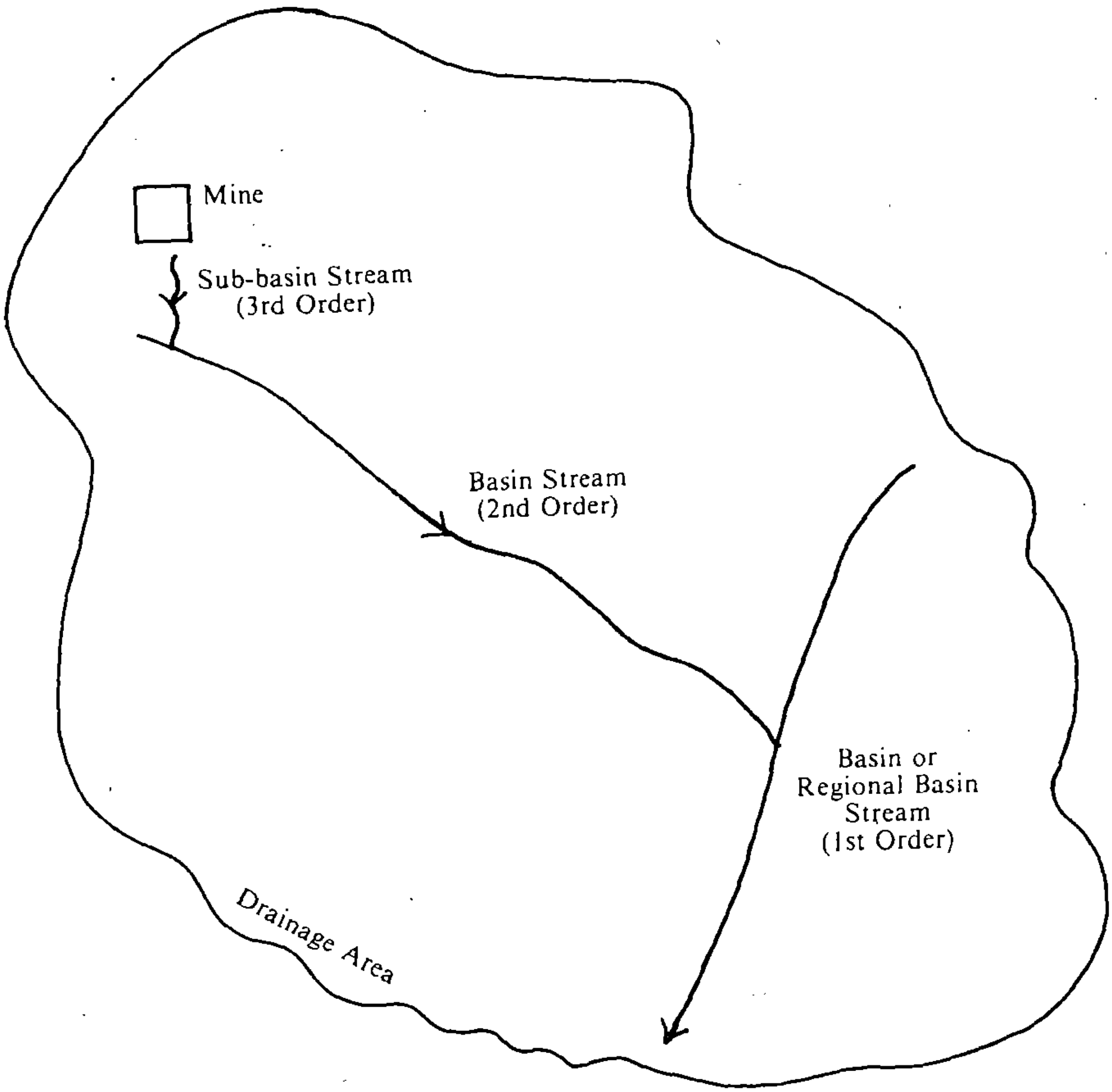

Figure J.1 Surface stream flow pattern within drainage area techniques for predicting water concentration should be quite conservative since they do not account for periods of no-flow in the third order streams nor for loss of radioactivity from the water by percolation into the soil.

The environmental transport pathways which are examined as potential contributors of dose equivalents and health effects to individuals and to the population are listed in Table J.1. It was found that essentially all potable drinking water in both the New Mexico and the Wyoming assessment areas is taken from groundwater supplies. Public water supplies are taken from aquifers below the elevation of the aquifers which could be affected by recharge from the mine surface water. For this reason, drinking water (pathway 1) is not considered as a pathway of exposure to the population. Drinking water could be a significant pathway of exposure for the maximum individual living near a uranium mine if he were drinking surface water downstream of the mine discharge point or water from a shallow aquifer which had been recharged by the mine surface water. However, this pathway was not assessed because it was not possible to quantify radionuclide concentrations in potable groundwater from mine discharges with available information. Also, it is believed that the occurrence of direct consumption by individuals of surface water containing mine discharges would be infrequent or nonexistent.

Through telephone conversations, it was learned that almost all milk cows in the assessment areas obtain their drinking water from groundwater supplies. In addition, most of the dairy cattle are located 50 km or more away from the uranium mines (Romo, T., Valencia County Agent, Los Lunas, NM, 1979, personal communication and Loper, R., Soil Conservation Service, U.S. Department of Agriculture, Douglas, WY, 1979, personal communication). For these reasons, consumption of milk produced by cows drinking contaminated water is not considered in the population dose equivalent calculations. Thus, the pathways listed in Table J-1 which are considered for the population dose equivalent calculations are 2 through 8 and 10. For the maximum individual dose equivalent calculations, the pathways considered are 2 through 10.

For these generic site analyses, detailed data are not readily available regarding fish catch and surface stream water usage as a function of distance downstream from the mine for the third, second, and first order streams.

Thus, a simplified approach is taken in computing the population dose equivalents and health effects. The population assessment area is defined as the areas draining into the streams shown in Fig. J.1. These drainage areas are discussed in more detail in Sections 3.3.3 and 3.4.3*. To compute the population dose equivalents and health effects, the assumption is made that the water concentrations in the first order stream are representative of the radionuclide concentrations to which persons within the assessment area could be exposed. The resulting river water concentrations of radionuclides are applied to each of the eight pathways for which population dose equivalents are calculated.

The mathematical models used for the population and maximum individual dose equivalents and health effects calculations will be discussed in the following paragraphs. Average individual dose equivalents and health effects are computed by dividing the population values by the number of persons in the assessment area. For each pathway, dose equivalents are calculated for endosteal cells (bone), red bone marrow, lung, liver, stomach wall, lower large intestine (LLI) wall, thyroid, kidney, muscle, ovaries, testes and a weighted mean dose equivalent which is weighted over all organs. For the external exposure pathways (pathways 7 and 8) these dose equivalents are used to estimate health impact by applying a dose-to-health-impact conversion factor. This factor is a function of organ and is independent of the nuclide involved. However, for all of the internal exposure pathways (pathways 1 through 6, 9, and 10) dose equivalents are calculated and reported only for the purpose of supplying this information to the reader. The health impact for each pathway is estimated by computing the quantity of each radionuclide taken in by the population or a maximum individual and applying an intake-to-health-impact conversion factor. This factor is a function of the nuclide involved but is not a function of organ. When estimates of health impacts have been computed for each pathway and radionuclide involved, they may be summed over pathways and radionuclides to obtain an estimate of total health impacts to the population, and the average and maximum individuals.

*For the Wyoming site, the assessment area is the 13,650 km^2 regional basin drainage area of the Cheyenne River discussed in Section 3.3.3.1.2. For the New Mexico site, the assessment area is the 19,037 km^2 basin drainage area of the Rio San Jose-Rio Puerco Rivers discussed in Section 3.4.3.1.2.

Table J.1 Aquatic environmental transport pathways examined

Pathway Number	Pathway
1	Drinking water ingestion
2	Freshwater fish ingestion
3	Above-surface crops ingestion -- Irrigated Cropland
4	Milk ingestion -- cows consuming forage raised on irrigated pastures
5	Beef ingestion -- cows consuming forage raised on irrigated pastures
6	Inhalation of resuspended material deposited during irrigation
7	External exposure due to ground contamination by material deposited during irrigation
8	External exposure due to air submersion in resuspended material originally deposited during irrigation
9	Milk ingestion -- cows drinking contaminated surface water
10	Beef ingestion -- cows drinking contaminated surface water

J.3 Freshwater Fish Ingestion

The computational equation for intake of a radionuclide by the maximum individual is

$$II_{np} = \frac{Q_n \cdot CF_n \cdot I_f}{R_{ind}} \qquad (J.1)$$

where,

II_{np} = annual intake of radionuclide n through pathway p for the maximum individual (Ci/y),

Q_n = release rate of radionuclide n to the third order stream (Ci/y),

CF_n = concentration factor for freshwater fish for radionuclide n (Ci/kg per Ci/ℓ),

I_f = freshwater fish annual consumption rate for an individual (kg/y), and

R_{ind} = flow rate in 2nd order stream (ℓ/y).

The maximum individual dose equivalent may be computed from the equation

$$DI_{nop} = II_{np} \cdot D_{nop} \qquad (J.2)$$

where,

DI_{nop} = dose equivalent rate to the maximum individual for nuclide n, organ o, and pathway p (rem/y), and

D_{nop} = dose equivalent conversion factor for nuclide n, organ o, and pathway p (rem/Ci intake unless specified otherwise).

The maximum individual increased health risk may be computed using the equation

$$IR_{np} = II_{np} \cdot HI_{np} \qquad (J.3)$$

where,

IR_{np} = increased annual health risk* rate to the maximum individual for nuclide n and pathway p (increase in risk per year of release), and

HI_{np} = health risk conversion factor for nuclide n and pathway p (increase in risk/Ci intake).

Equation J.3 may be applied for computing either fatal cancer risk or genetic risk *to future generations by applying* HI_{np} *for fatal cancer risk or* genetic risk, respectively.

The equation used to compute total intake of a radionuclide by the population was

$$IP_{np} = \frac{Q_n \cdot CF_n \cdot I_f \cdot P_{ff}}{R}, \qquad (J.4)$$

where,

IP_{np} = annual intake of radionuclide n through pathway p for the population (person Ci/y),

R = flow rate in 1st order stream (ℓ/y), and

P_{ff} = population eating freshwater fish taken from streams in the assessment area (persons).

The population dose equivalent may be computed from the equation

$$DP_{nop} = IP_{np} \cdot D_{nop} \qquad (J.5)$$

where,

DP_{nop} = annual dose equivalent to the population for nuclide n, organ o, and pathway p (person-rem/y);

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*The term health risk is used to describe the increase in fatal cancer risk to an individual during his lifetime for somatic risks. For genetic risk, the term health risk refers to the increased chance for genetic defects in all the decendants of an exposed individual.

and the annual health effects to the population may be computed using the equation

$$PR_{np} = IP_{np} \cdot HI_{np} \tag{J.6}$$

where,

PR_{np} = annual health effects to the population for nuclide n and pathway p (health effects /y of release).

Equation J.6 may be applied for computing either fatal cancers or genetic effects to future generations by applying the proper value for HI_{np}, as discussed above.

The annual dose equivalent and increased health risk to an average individual may be computed using equations J.7 and J.8, respectively.

$$DAI_{nop} = DP_{nop}/P_T \tag{J.7}$$

$$AIR_{np} = PR_{np}/P_T \tag{J.8}$$

where,

DAI_{nop} = annual dose equivalent to the average individual within the assessment area for nuclide n, organ o, and pathway p (rem/y),

AIR_{np} = increased annual risk to the average individual for nuclide n and pathway p (increase in risk per year of release), and

P_T = size of population residing within the assessment area (persons).

J.4 <u>Above-Surface Crops, Milk, and Beef Ingestion - Irrigated Crop Land</u>

The equation used to compute intake of a radionuclide by the maximum individual was

$$II_{np} = \frac{Q_n \cdot W \cdot RI_{np}}{R_{ind}} \tag{J.9}$$

where,

W = irrigation rate of irrigated farmland (ℓ/m^2-y), and

RI_{np} = intake rate of radionuclide n by standard man for above-surface crops and for a continuous deposition rate to the surface for root uptake due to ditch irrigation (Ci intake/y per Ci/m^2-y deposited).

The approach for calculation of RI_{np} uses techniques described in Regulatory Guide 1.109 (NRC77) and AIRDOS-EPA (Mo79) to compute intake rate by receptors per unit deposition rate (by ditch irrigation) to the ground surface. Basically, equations 49 (vegetation), 51 (milk), or 52 (beef) from the AIRDOS-EPA document (Mo79) are utilized to predict concentrations of radionuclides in the foodstuffs at equilibrium. Only the root uptake portion of these equations is used since essentially all irrigation in the assessment areas is ditch irrigation (Romo, T., Valencia County Agent, Los Lunas, NM., 1979, personal communication, and Loper, R., Soil Conservation Service, U.S. Department of Agriculture, Douglas, WY, 1979, personal communication). The effects of removal of radionuclides from the soil root zone by leaching are added to the equations used to predict concentrations of radionuclides in foodstuffs since this is an important removal mechanism for the long-lived radionuclides considered in this analysis. The concentrations are multiplied by the annual intake rate of the foodstuff by an individual and divided by the annual deposition rate of radionuclides to the ground surface to yield the quantity RI_{np}. The maximum individual dose equivalents may be computed using equation J.2 and the increased health risk to the maximum individual may be computed using equation J.3.

The equation to use in computing total intake of a radionuclide by the population is

$$IP_{np} = \frac{Q_n \cdot W \cdot RI_{np} \cdot P_p}{R} \qquad (J.10)$$

where,

P_p = population consuming foodstuffs raised on irrigated land (persons).

P_p can be determined using the equation

$$P_p = CP_p \cdot f_p \cdot A_I \qquad (J.11)$$

and the ratio can be written

$$W/R = \frac{R_I}{A_I \cdot R} = \frac{f_R}{A_I} \tag{J.12}$$

where,

CP_p = persons per unit area that can be fed from foodstuff p raised on irrigated land (persons fed/m^2),

f_p = fraction of irrigated land used to raise foodstuff p,

A_I = irrigated land area within the assessment area (m^2),

R_I = total flow of irrigation water (ℓ/yr), and

f_R = $\frac{R_I}{R}$ = fraction of river flow used for irrigation.

Substituting equations J.11 and J.12 into J.10 and cancelling like terms yields

$$IP_{np} = Q_n \cdot f_R \cdot RI_{np} \cdot CP_p \cdot f_p. \tag{J.13}$$

The population annual dose equivalents may be computed using equation J.5 and the annual increased health effects to the population may be computed using equation J.6. The annual dose equivalents and increased health risks to an average individual may be computed using equations J.7 and J.8.

J.5 Inhalation of Resuspended Material Deposited During Irrigation

In determining the equations to use to model resuspension of radioactive materials deposited by irrigation water, it is assumed that the resuspended material does not disperse beyond the irrigation area. This assumption should be acceptable for dose equivalent and health effects calculations where the irrigation area is large compared to a point resuspension source and where the population density does not vary greatly within an assessment area. Both of these criteria are met for the New Mexico and the Wyoming assessment areas.

Figure J.2 shows, pictorially, the conservation of mass relationship used in the resuspension model. The differential equation which expresses the change in soil surface concentration as a function of time is

$$\frac{d\Omega_n}{dt} = \frac{Q_n \cdot W}{R} + v_{gn} \cdot \chi_n - \lambda_R \Omega_n - \lambda_{Dn} \Omega_n - \lambda_{sn} \Omega_n \tag{J.14}$$

where,

Ω_n = ground concentration of nuclide n at time t (Ci/m^2),

t = time after release of material to surface stream (y),

v_{gn} = deposition velocity from air to land surface (m/y),

X_n = air concentration of nuclide n (Ci/m^3),

λ_R = rate constant for resuspension of radionuclides from soil to air (y^{-1}),

λ_{Dn} = radioactive decay constant for radionuclide n (y^{-1}),

λ_{sn} = rate constant for transfer of radionuclides from available to unavailable status in soil (y^{-1}),

and the other terms are as previously defined.

If it is further assumed that, at equilibrium, the material resuspended from the ground surface is equal to the material redeposited to the ground surface (i.e., $v_{gn}X_n = \lambda_R\Omega_n$), the differential equation can be simplified to yield

$$\frac{d\Omega_n}{dt} = \frac{Q_n \cdot W}{R} - (\lambda_{Dn} + \lambda_{sn})\Omega_n \qquad (J.15)$$

Equation J.15 would rigorously hold only for equilibrium conditions. It can be shown that it is conservative to apply the nonequilibrium initial conditions, $\Omega_n = 0$ at $t = 0$, in solving equation J.15 to yield

$$\Omega_n = \frac{Q_n \cdot W}{R(\lambda_{Dn}+\lambda_{sn})} [1-e^{-(\lambda_{Dn} + \lambda_{sn})t}]$$

When using equation J.16 in computations involving the maximum individual, R is replaced by R_{ind}.

As mentioned previously, assuming a fairly large uniformly contaminated area, the air concentration of radionuclides due to resuspension can be expressed as

$$X_n = RF \cdot \Omega_n \qquad (J.17)$$

where,

$RF = \lambda_R/v_{gn}$ = resuspension factor (m^{-1}).

Combining equations J.16 and J.17 yields

$$X_n = \frac{Q_n \cdot W \cdot RF}{R(\lambda_{Dn} + \lambda_{sn})} [1-e^{-(\lambda_{Dn} + \lambda_{sn})t}] \qquad (J.18)$$

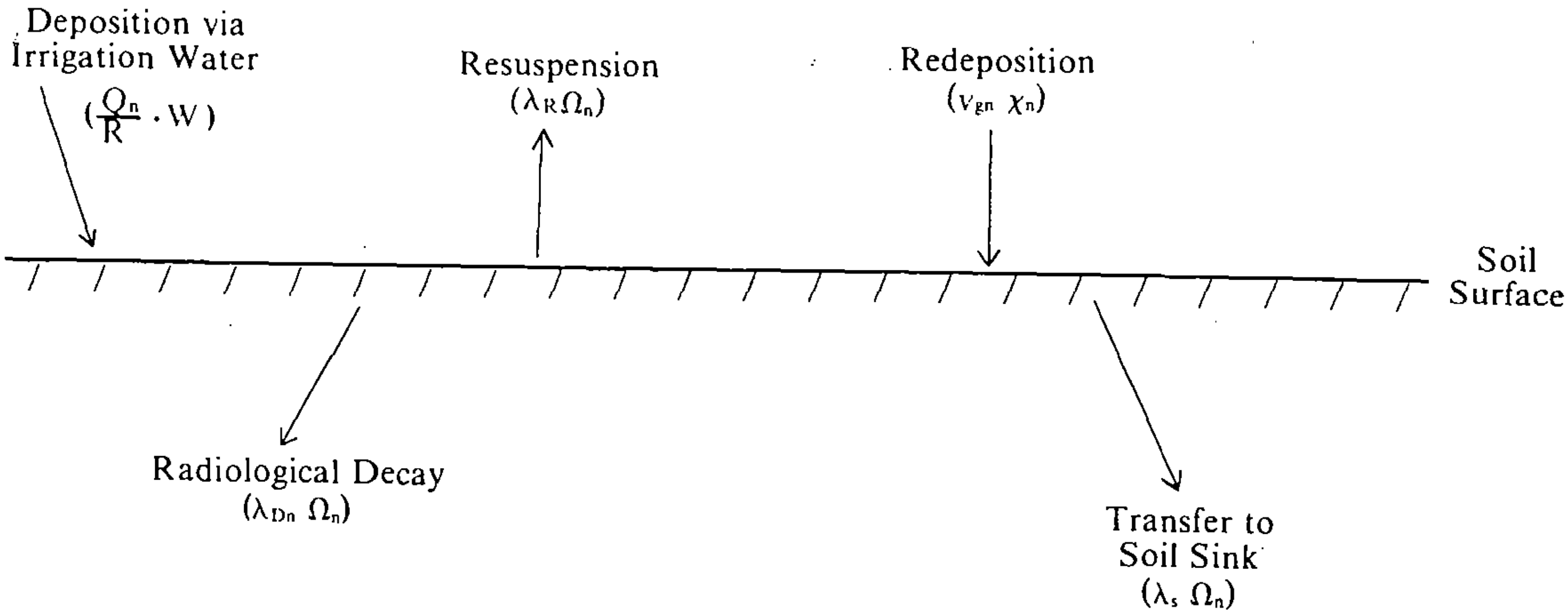

Figure J.2 Conservation of mass relationship for resuspension model

This equation is appropriate to apply for the population dose equivalent calculations. For calculations involving the maximum individual, R is replaced by R_{ind}.

The equation used to compute intake of a radionuclide by the maximum individual is

$$II_{np} = X_n I_B \tag{J.19}$$

where,

I_B = breathing rate for standard man (m^3/y).

Combining equations J.18 and J.19 yields

$$II_{np} = \frac{Q_n \cdot W \cdot RF \cdot I_B}{R_{ind}\ (\lambda_{Dn} + \lambda_{sn})} \left[1-e^{-(\lambda_{Dn} + \lambda_{sn})t}\right] \tag{J.20}$$

The maximum individual annual dose equivalents may be computed using equation J.2 and the maximum individual annual increased health risks may be computed using equation J.3.

The equation to use in computing total intake of a radionuclide by the population is

$$IP_{np} = X_n \cdot I_B \cdot p \cdot A_I \tag{J.21}$$

where,

p = population density within the assessment area ($person/m^2$).

After substitution of equations J.18 and J.12, we have

$$IP_{np} = \frac{Q_n \cdot f_R \cdot RF \cdot I_B \cdot P}{(\lambda_{Dn} + \lambda_{sn})} \left[1-e^{-(\lambda_{Dn} + \lambda_{sn})t}\right]. \tag{J.22}$$

The annual population dose equivalents may be computed using equation J.5 and the annual increased health effects to the population may be computed using equation J.6. The annual dose equivalents and increased health risks to an average individual may be computed using equations J.7 and J.8.

J.6 External Exposure Due to Ground Contamination by Material Deposited from Irrigation Water

As was discussed earlier, health risks are computed from dose equivalents for the external exposure pathways. The equation used in computing annual dose equivalents to the maximum individual is

$$DI_{nop} = \Omega_n \cdot D_{nop} \cdot SOF \tag{J.23}$$

where,

D_{nop} = dose equivalent factor for external ground contamination for nuclide n, organ o, and pathway p (rem/y per Ci/m^2), and

SOF = household shielding and occupancy factor (dimensionless).

Upon substitution of equation J.16 we have (substituting R_{ind} for R)

$$DI_{nop} = \frac{Q_n \cdot W \cdot D_{nop} \cdot SOF}{R_{ind}\,(\lambda_{Dn} + \lambda_{sn})} \left[1-e^{-(\lambda_{Dn} + \lambda_{sn})t}\right]. \tag{J.24}$$

The increase in annual health risks for the maximum individual can be computed using the equation

$$IR_{nop} = DI_{nop} \cdot HE_{op} \tag{J.25}$$

where,

IR_{nop} = increased annual risk to the maximum individual for nuclide n, *organ o, and pathway p (increase in risk/year of release), and*

HE_{op} = health risk conversion factor for external doses for organ o and pathway p (increase in risk/rem).

The equation for computing annual external population dose equivalents due to uniform ground contamination is

$$DP_{nop} = \Omega_n \; D_{nop} \cdot SOF \cdot p \cdot A_I \tag{J.26}$$

Substitution of equations J.16 and J.12 into this equation yields

$$DP_{nop} = \frac{Q_n \cdot f_R \cdot D_{nop} \cdot SOF \cdot p}{(\lambda_{Dn} + \lambda_{sn})} [1-e^{-(\lambda_{Dn} + \lambda_{sn})t}]. \qquad (J.27)$$

For equations J.24 and J.27, the exposed persons are represented as a point receptor 1 m above a plane surface with a uniform distribution of radioactivity. The increase in health risks for the population are estimated using the equation

$$PR_{nop} = DP_{nop} \cdot HE_{op} \qquad (J.28)$$

where,

PR_{nop} = increased annual health effects to the population for nuclide n, organ o, and pathway p (health effects /y of release).

The annual dose equivalents and increased health risks to an average individual may be computed using equations J.7, and J.29, respectively:

$$AIR_{nop} = PR_{nop}/P_T \qquad (J.29)$$

where,

AIR_{nop} = annual increased health risk to the average individual for nuclide n, organ o, and pathway p (increase in risk/year of release).

J.7 External Exposure Due to Air Submersion in Resuspended Material Originally Deposited During Irrigation

The equation applied in calculating maximum individual annual external dose equivalents due to submersion is

$$DI_{nop} = X_n \cdot \bar{D}_{nop} \cdot SOF \qquad (J.30)$$

where,

D_{nop} = dose equivalent conversion factor for external air submersion for nuclide n, organ o, and pathway p (rem/y per Ci/m^3).

Upon combining equations J.30 and J.18, the dose equivalent rate equation becomes

$$DI_{nop} = \frac{Q_n \cdot W \cdot RF \cdot D_{nop} \cdot SOF}{R_{ind} (\lambda_{Dn} + \lambda_{sn})} [1-e^{-(\lambda_{Dn} + \lambda_{sn})t}]. \tag{J.31}$$

The increase in annual health risks for the maximum individual can be computed using equation J.25.

The equation for computing external population annual dose equivalents due to air submersion is

$$DP_{nop} = X_n \cdot D_{nop} \cdot SOF \cdot p \cdot A_I \tag{J.32}$$

Substitution of equations J.18 and J.12 into equation J.32 yields

$$DP_{nop} = \frac{Q_n \cdot f_R \cdot RF \cdot D_{nop} \cdot SOF \cdot p}{(\lambda_{Dn} + \lambda_{sn})} [1-e^{-(\lambda_{Dn} + \lambda_{sn})t}]. \tag{J.33}$$

Equations J.31 and J.33 are derived assuming a point receptor immersed in a semi-infinite hemispherical cloud of air in which the distribution of activity is spatially uniform.

The increase in annual health risks for the population are estimated using equation J.28. The annual dose equivalent and increased health risk to an average individual may be computed using equations J.7 and J.29, respectively.

J.8 Milk Ingestion--Cows Drinking Contaminated Surface Water

The computational equation for intake of a radionuclide by the maximum individual is

$$II_{np} = \frac{Q_n \cdot I_{wm} \cdot F_{mn} \cdot I_{mF}}{R_{ind}} \tag{J.34}$$

where,

I_{wm} = milk cow drinking water ingestion rate (ℓ/d),

F_{mn} = concentration of radionuclide n in the milk per unit daily intake of the radionuclide via cattle drinking water (Ci/ℓ milk per Ci/day), and

I_{mF} = adult consumption rate of milk (ℓ/y).

The maximum annual individual dose equivalents may be computed from equation J.2 and the maximum annual individual increased health risks may be computed using equation J.3. Annual population dose equivalents and increased health impacts were not calculated for this pathway since it was determined that consumption of contaminated drinking water by milk cows would be infrequent or nonexistent.

J.9 Beef Ingestion--Cows Drinking Contaminated Surface Water

The computational equation for intake of a radionuclide by the maximum individual is

$$II_{np} = \frac{Q_n \cdot I_{WB} \cdot F_{Bn} \cdot I_{BF}}{R_{ind}} \tag{J.35}$$

where,

I_{WB} = beef cattle drinking water ingestion rate (ℓ/d),

F_{Bn} = concentration of radionuclide n in beef per unit daily intake of the radionuclide via cattle drinking water (Ci/kg beef per Ci/day), and

I_{BF} = adult consumption rate of beef (kg/y).

The maximum individual annual dose equivalents may be computed from equation J.2 and the maximum individual annual increased health risks may be computed using equation J.3.

For computing total intake of a radionuclide by the population, the appropriate equation is

$$IP_{np} = \frac{Q_n \cdot I_{WB} \cdot F_{Bn} \cdot I_{BF} \cdot P_{BW}}{R} \qquad (J.36)$$

where,

P_{BW} = number of persons eating beef from cows which drink contaminated water (persons).

The annual population dose equivalents may be computed from equation J.5 and the annual increased health effects to the population may be computed using equation J.6. The annual dose equivalents and increased health risks to an average individual may be computed using equations J.7 and J.8, respectively.

J.10 Generic Sites

Two generic sites were chosen to represent locations where uranium mines may be located. A generic site in Converse County, Wyoming, was chosen to represent typical surface mine sites and one in Valencia County, New Mexico, was chosen to represent typical underground mining sites. Figure J.1 shows the general assessment area for both generic sites. These sites are described more fully in Sections 3.3.3 and 3.4.3 and in Subsection J.2 of this appendix. Some of the characteristics of these sites used in the dose equivalent and health effects calculations are listed in Table J.2.

Table J.2 Characteristics of the generic sites

	New Mexico	Wyoming
Annual rainfall (cm)	20	28
Total population in assessment area	64,950	16,230
Population density in assessment area (persons/m^2)	3.41×10^{-6}	1.19×10^{-6}
Assessment area size (km^2)	19,037	13,650
Streams within assessment area[a] (avg. annual flow rate, ℓ/yr)	Arroyo del Puerto-San Mateo Creek	Not named
Third order	(small)	(small)
Second order	Rio San Jose (5.83×10^{9})	Lance Creek (2.18×10^{10})
First order	Rio Puerco (4.26×10^{10})	Cheyenne, Dry Fork (5.64×10^{10})
Number of persons eating fish containing radionuclides from mine discharges	6,495	1,623
Annual irrigation rate within assessment areas (m)	1.07(b)	0.59
Fraction of annual-average first order stream flow used for irrigation	0.30	0.29
Land area irrigated within assessment area (km^2)	12[b]	28
Number of persons eating beef from cows drinking contaminated water	38,510	3,454

(a)See Sections 3.3.3 and 3.4.3 for a full discussion of assessment area streams and hydrology.

(b)Some groundwater used for irrigation. See discussion in Subsection J.13.

J.11 Population and Population Density in Assessment Areas

For both generic sites, the population within the assessment area is determined by computing the population density for a county containing a significant part of the assessment area and then scaling this population density up to the assessment area size. For New Mexico, Valencia County data are used (Romo, T., Valencia County Agent, Los Lunas, NM, 1979, personal communication). The current population of Valencia County is about 50,000 persons. The county area is 14,650 km^2. The population density, based on these data, is 3.41×10^{-6} persons/m^2. Considering the size of the assessment area to be 19,037 km^2 (Section 3.4.3), the estimated total population in the assessment area is 64,950 persons. For Wyoming, Converse County data are applied (Zaborac, J., Converse Area Planning Office, Douglas, WY, 1979, personal communication). The estimated current population of Converse County is 13,000 persons and the county area is 10,930 km^2. Thus, the population density is calculated to be 1.19×10^{-6} persons/m^2. The assessment area contains 13,650 km^2 (Section 3.3.3); therefore, the total population within the Wyoming assessment area is estimated to be 16,230.

J.12 Population Consuming Fish Containing Radionuclides Discharged from Mines

Information on fish catch specific to the assessment areas is not available. However, three sources agreed that there is very little fishing activity in the streams in these areas (Patterson, R., New Mexico Game and Fish Department, Santa Fe, NM, 1979, personal communication; Baughman, J., Wyoming Game and Fish Division, Cheyenne, WY, 1979, personal communication; and Kaufmann, R., U.S. Environmental Protection Agency, Office of Radiation Programs, Las Vegas Facility, Las Vegas, NV, 1979, personal communication). Considering these data and the lack of specific information, it is assumed that 10 percent of the population within each assessment area consumes fish taken from streams within the assessment area. Based on the hydrologic characteristics of these areas, this is probably a conservative assumption.

J.13 Irrigation Within the Assessment Areas

For the New Mexico site, the following irrigation information was obtained for Valencia County (Romo, T., Valencia County Agent, Los Lunas, NM, 1979, personal communication). Valencia County is a very large county and the Rio Grande flows through the eastern part of the county at a distance of about 100 km from the uranium mine site. Since it is known that a large amount of irrigation within the county occurs along the Rio Grande and since the Rio Grande was not included in the assessment area, the effect of the irrigation along the Rio Grande was extracted from the county data in estimating the amount of irrigated land within the assessment area. The calculational procedure is described below.

The three major streams for irrigation in Valencia County are the Rio San Jose (second order), the Rio Puerco (first order), and the Rio Grande. The average irrigation rate is 1.07 m/yr. Within Valencia County, 11,234 hectares are irrigated with surface water only, and 5,306 hectares use a combination of surface water and groundwater for irrigation. It is assumed that for this 5,306 hectares 50 percent of the irrigation water is surface water and 50 percent of this is groundwater that does not contain mine-related radionuclides. To calculate the equivalent acres of land totally irrigated from the Rio San Jose and the Rio Puerco within Valencia County we assume that the amount of irrigation existing along a stream is directly proportional to the product of the annual-average flow rate and the length of the stream within the county. Thus a ratio is established to predict the fraction of total land irrigated in Valencia County that is irrigated from the Rio San Jose and the Rio Puerco. The data applied in calculating this ratio are listed in Table J.3.

The ratio is

$$\frac{47.5(4.3\text{x}10^{7}) + 132.5(5.8\text{x}10^{6})}{47.5(4.3\text{x}10^{7}) + 132.5(5.8\text{x}10^{6}) + 45(8.7\text{x}10^{8})} = 0.067.$$

Then the equivalent land irrigated using surface water from the Rio San Jose and Rio Puerco in Valencia County is 11,234 (0.067) + 5,306 (0.5)(0.067) = 930 hectares. Scaling this up to the assessment area size using the ratio of assessment area size to Valencia County size yields:

Table J.3 Stream data for Valencia County

Stream	Length Within Valencia County (km)	Annual Average Flow Rate (m^3/yr)
Rio San Jose	132.5	5.8×10^6
Rio Puerco	47.5	4.3×10^7
Rio Grande	45	8.7×10^8

$$930 \text{ hectares} \times \frac{19{,}037}{14{,}650} \times \frac{0.01 \text{ km}^2}{\text{hectares}} = 12.1 \text{km}^2.$$

The surface water usage to irrigate this land (1.07 m/y) is 1.29×10^{10} ℓ/y and the fraction of the river flow in the first order stream that the surface water irrigation represents is $1.29 \times 10^{10}/4.26 \times 10^{10} = 0.30$.

For the Wyoming site, the area of land irrigated within the assessment area is given in Section 3.3.3 as 2,800 hectares (28 km^2). This land is irrigated almost entirely with surface water (Loper, R., Soil Conservation Service, U.S. Department of Agriculture, Douglas, WY, 1979, personal communication). The average irrigation rate within the area is $0.588 \frac{m^3}{m^2\text{-}y}$ (WSG77).

Thus the estimated total irrigation water usage within the assessment area is

$$(0.588 \frac{m}{y})(2.8\times10^7 m^2) = 1.65 \times 10^7 \frac{m^3}{y} = 1.65 \times 10^{10} \text{ ℓ/yr}.$$

Then, the fraction of the first order stream flow that is used for irrigation is $1.65 \times 10^{10}/5.6 \times 10^{10} = 0.29$.

J.14 Population Consuming Beef from Cattle Drinking Water Containing Radionuclides Discharged from the Uranium Mine

For the New Mexico site, information on beef consumption is taken from the USDA (DOA73), (Herman, J., Statistician-in-Charge, New Mexico Crop and Livestock Reporting Service, U.S. Department of Agriculture, Las Cruces, NM, 1979, personal communication). The term "beef" is a misnomer in that total red meat consumption is actually considered in these calculations. Since well over 50 percent of the red meat production is beef, the calculations are simplified by assuming that all meat production, excluding poultry, is beef for the purpose of this assessment. Table J.4 shows the computational procedure used to estimate the total meat production for Valencia County for 1977. Using this information, the total edible meat production for the assessment area can be estimated as

$$\frac{19{,}037\ \text{km}^2}{14{,}650\ \text{km}^2}\ (5.038 \times 10^6\ \text{kg/y}) = 6.547 \times 10^6\ \text{kg/y}.$$

It is estimated that about 50 percent of the water drunk by meat producing animals in the assessment area is surface water and 50 percent uncontaminated groundwater (Kaufmann, R., U.S. Environmental Protection Agency, Office of Radiation Programs, Las Vegas Facility, Las Vegas, NV, 1979, personal communication). Then the weight of edible meat from animals drinking surface water containing mine effluents is 3.273×10^6 kg/y. Since it is estimated that an adult eats 85 kg/y of meat (Mo79), the number of persons eating meat from animals raised in the assessment area which drink water containing mine effluent is 38,510 persons.

For the Wyoming site, information on meat consumption was obtained from the USDA (DOA79). The information listed in Table J.5 shows the computational procedure used to estimate the meat production for Converse County for 1976. Thus, the total edible meat production for the assessment area can be estimated as

$$\frac{13{,}650\ \text{km}^2}{10{,}930\ \text{km}^2}\ \left(469{,}700\ \frac{\text{kg}}{\text{y}}\right) = 5.866 \times 10^5\ \frac{\text{kg meat}}{\text{y}}.$$

J.4 Estimation of meat production in Valencia County for 1977

Animal	1977 NM State Live Weight Slaughter[a] (kg)	Edible Fraction Live Weight[b]	1977 NM State Edible Meat, Computed from Col. 2 and 3 (kg)	Total Animals on Pasture Jan. 1, 1973[c] NM State	Total Animals on Pasture Jan. 1, 1973[c] Valencia County	Ratio of Animals on Pasture, Valencia County ÷ New Mexico State (Computed from Col. 5 and 6)	Estimated Edible Meat Production for Valencia County (Computed from Col. 4 and 7) (kg/y)
1	2	3	4	5	6	7	8
Cattle	260,813,700	.55	143,447,500	1,615,000	54,000	0.0334	4,791,000
Hogs	8,862,900	.65	5,760,880	63,000	1,500	0.0238	137,100
Sheep	4,487,460	.55	2,468,110	743,000	30,000	0.0404	99,700
				Total Edible Meat Valencia County			5,027,800

(a) Herman, J., Statistician-in-Charge, New Mexico Crop and Livestock Reporting Service, U.S. Department of Agriculture, Las Cruces, NM, 1979, personal communication.

(b) Walsh, P., Statistician-in-Charge, Alabama Crop and Livestock Reporting Service, U.S. Department of Agriculture, 1979, personal communication.

(c) DOA73.

Table J.5 Estimation of meat production in Converse County, Wyoming for 1976

Animals	1976 Wyoming State Red Meat Production[a] (kg)	Total Animals on Pasture Jan. 1, 1976[a]		Ratio of Animals on Pasture, Converse County ÷ Wyoming State (Computed from Col. 3 and 4)	Estimated Edible Meat Production for Converse County (Computed from Col. 2 and 5) $\frac{(kg)}{y}$
		Wyoming State	Converse County		
1	2	3	4	5	6
Cattle	--	1,580,000	74,000	0.0468	--
Red Meat Animals (Cattle, hogs, and sheep)	10,028,200	--	--	0.0468[b]	469,300

[a] DOA79.

[b] Applied value for cattle since cattle furnish the majority of the red meat production for Converse County and for the State of Wyoming.

As for New Mexico, it was estimated that about 50 percent of the water drunk by meat producing animals in the assessment area is surface water and 50 percent uncontaminated groundwater (Loper, R., Soil Conservation Service, U.S. Department of Agriculture, Douglas, WY, 1979, personal communication). Thus, the estimated weight of edible meat from animals drinking surface water containing mine effluents is 293,500 kg meat/y. Using the 85 kg/y adult meat consumption rate (Mo79) used for New Mexico, the number of persons eating meat from animals raised in the assessment area which drink water containing mine effluent is 3,454 persons.

J.15 <u>Radionuclide Releases</u>

For both the New Mexico and the Wyoming sites, radionuclide releases are given for "total uranium" and radium-226 in Tables 3.44 and 3.25, respectively. The total uranium releases are kg per year. This "total uranium" will be almost totally U-238 by weight. For this reason, it is assumed that the "total uranium" release is entirely U-238. Further assumptions are that U-234 is in secular equilibrium with U-238 but that Th-230 precipitates out of the mine water. Also, it is assumed that Rn-222, Pb-214, Bi-214, Pb-210, and Po-210 are in secular equilibrium with Ra-226. The radionuclides Pa-234m, Pa-234, Po-218, At-218, Po-214, Tl-210, Bi-210 and Tl-206 are not included in the analysis because they are not dosimetrically significant or they have very low branching ratios.

The total uranium release rate for New Mexico is listed as 1,480 kg/y-mine. The conversion from kg to Ci for U-238 is 3.336×10^{-4} Ci/kg. Using this factor, the estimated release rate of U-238 is 0.494 Ci/y-mine. The release rate for Ra-226 is 0.0144 Ci/y-mine. The total uranium release rate at the Wyoming site is listed as 110 kg/y-mine. Using the conversion factor, this release rate can be stated as 0.0367 Ci/y-mine. The Ra-226 release rate is 0.0065 Ci/y-mine.

As discussed in Section 3.3.3.1.4, radium-226 is strongly sorbed onto stream sediments and is subject to precipitation. For these reasons, it is assumed that only 10% of the Ra-226 released in mine discharges is still available in surface water in the second and first order streams. Thus, the "effective" annual release of Ra-226 is 10% of the actual releases in mine water. Using the assumptions regarding secular equilibrium stated above, the radionuclide release rates used in the analyses for both sites are listed in Table J.6.

J.16 Fish Concentration Factors

The fish concentration factors express the ratio of radionuclide level in freshwater fish (Ci/kg) per unit concentration in water (Ci/ℓ). The values used for this parameter are suggested by Thompson (Th72) and are listed in Table J.7.

J.17 Fish Consumption and Air Inhalation Rates

The freshwater fish consumption for an individual is taken as 1.0 kg/y which is the value used in the report by the United Nations Scientific Committee on the Effects of Atomic Radiation (UN77). This value is not specifically stated in Regulatory Guide 1.109 (NRC77). The breathing rate for an individual of 8030 m^3/y (Mo79) is used for this analysis. This value is in close agreement with the value of 8,000 m^3/y listed in Regulatory Guide 1.109.

J.18 Stream Flow Rates

As was noted in Section J.2, second order stream flow rates were used in computing maximum individual dose equivalents. These flow rates are listed in Table J.2. For the New Mexico site, the second order stream flow rate is 5.83×10^9 ℓ/y and for the Wyoming site it is 2.18×10^{10} ℓ/y. First order stream flow rates are considered to be more representative for computations involving the population and an average individual. These flow rates are also listed in Table J.2 and are 4.26×10^{10} ℓ/y for the New Mexico site and 5.64×10^{10} ℓ/y for the Wyoming site.

J.19 Normalized Human Intake Rate Factors

The normalized human intake rate factors, RI_{np}, express the intake rate of radionuclide n by standard man from consumption of above-surface crops, milk, and beef for a continuous deposition rate to the surface. For this

Table J.6 Annual radionuclide release rates to streams for active uranium mines

Nuclide	Release Rates for 1 Mine (Ci/y-mine)	
	New Mexico Site	Wyoming Site
U-238	0.494	0.0367
U-234	0.494	0.0367
Th-230	0	0
Ra-226	0.00144	0.00065
Rn-222	0.00144	0.00065
Pb-214	0.00144	0.00065
Bi-214	0.00144	0.00065
Pb-210	0.00144	0.00065
Po-210	0.00144	0.00065

Table J. 7 Freshwater fish concentration factors

Nuclide	Concentration Factor (Ci/Kg ÷ Ci/ℓ)
U-238	2
U-234	2
Ra-226	50
Rn-222	57
Pb-214	100
Bi-214	15
Pb-210	100
Po-210	500

pathway, the source of deposition to the surface is irrigation of farmland. Only the quantity of radionuclides taken up through the root systems of plants is considered in deriving these factors since essentially all irrigation in the assessment areas is ditch irrigation. The method used to calculate these factors was discussed in Section J.4 of this appendix and is taken from the AIRDOS-EPA computer code. The values for various parameters used in computing RI_{np} for above-surface crops, milk, and beef are discussed in the AIRDOS-EPA manual (Mo79). The normalized human intake rate factors are tabulated in Table J.8.

J.20 Persons Fed from Foodstuffs Raised on Irrigated Land and Irrigated Land Usage

The number of persons who can be fed from a unit area of irrigated land for above-surface crops, milk, and beef is determined from data contained in the AIRDOS-EPA computer code (Mo79). The values used for these analyses are, in units of persons fed/m^2, 3.69×10^{-3} for above-surface crops, 1.76×10^{-3} for milk, and 1.16×10^{-4} for beef. In both New Mexico and Wyoming, irrigated farmland is used for raising above surface foods for direct consumption by humans and for raising silage for consumption by both milk and beef cows. After telephone conversations with both the New Mexico and Wyoming county agents, the fractions of irrigated land supporting above-surface crops, dairy farming, and beef farming (see Table J.9) were determined (Romo, T., Valencia County Agent, Los Lunas, NM, 1980, personal communication and Henderson, F. Converse County Agent, Douglas, WY, 1980, personal communication).

J.21 Resuspension Factor

The irrigated areas within the assessment sites are assumed to be relatively large, uniformly contaminated areas. For this situation, the resuspension factor (RF) is defined as the ratio of air concentration above a surface to ground surface concentration. It can be shown that this ratio is $RF = \lambda_R/v_{gn}$. The resuspension rate constant, λ_R, can vary over a wide range of values between 10^{-7} and 10^{-11} sec^{-1} (Ne78). Since resuspension for this analysis is confined to irrigated land which should have a relatively damp surface, it is believed that a low resuspension rate should be used. The resuspension rate constant chosen for this analysis is $\lambda_R = 10^{-11}$ sec^{-1}. The deposition velocity to the ground surface (v_{gn}) can vary from values as low as 0.001 m/sec to as high as 0.1 m/sec (Sl68). For generic analyses where

Table J.8 Normalized human intake rate factors for radionuclide uptake via plant root systems

Nuclide	RI_{np} (Ci/day intake per Ci/m^2-day deposited)		
	Above Surface Crops	Milk	Beef
U-238	3.21×10^{-2}	2.02×10^{-4}	1.75×10^{-6}
U-234	3.21×10^{-2}	2.02×10^{-4}	1.75×10^{-6}
Ra-226	1.90×10^{-2}	3.93×10^{-3}	2.53×10^{-3}
Rn-222	6.39×10^{-1}	4.61×10^{-1}	3.49×10^{-1}
Pb-214	3.68×10^{-2}	8.40×10^{-4}	6.66×10^{-3}
Bi-214	8.43×10^{-1}	1.51×10^{-2}	3.92×10^{-1}
Pb-210	2.98×10^{-2}	7.51×10^{-4}	5.23×10^{-3}
Po-210	1.97×10^{-3}	3.42×10^{-5}	1.88×10^{-3}

Table J.9 Irrigated land usage

Type of food	Fraction of irrigated land used to raise each type of food	
	New Mexico	Wyoming
Above-surface crops	0.70	0.10
Milk	0.15	0.45
Beef	0.15	0.45

the site specific value is not known, a commonly chosen value for v_{gn} is 0.01 m/sec, and this is the value used in this analysis. The value for RF inferred from the values chosen for λ_R and v_{gn} is

$$RF = \lambda_R/v_{gn} = \frac{10^{-11}\ sec^{-1}}{0.01\ m\ sec^{-1}} = 10^{-9}/m$$

J.22 Soil Removal Rate Constant

The soil removal rate constant from available to unavailable soil (λ_{sn}) expresses the rate of movement of radionuclides from the plant root zone in soil to the soil below the root zone. The values used in this analysis are based upon a method described by Baes (Ba79). The soil removal rate constants were computed using the data suggested by Baes except that values for the distribution coefficients for the nuclides not discussed by Baes were taken from a report by the Arthur D. Little Company (EPA77). The values used for the soil removal rate constant in this analysis are listed in Table J.10.

J.23 Radionuclide Decay Constants

The radionuclide decay constants express the rate of radioacitve decay for the nuclides considered in this analysis. The values of this parameter for these nuclides are listed in Table J.10 and are derived using the half-lives given in the Radiological Health Handbook (HEW70). Since secular equilibrium was assumed (see J.15), the radionuclide decay constant for Ra-226 was used for its short-lived daughter products.

J.24 Shielding and Occupancy Factor

The shielding and occupancy factor is used to account for shielding of persons by buildings during the time that they spend indoors. It is also used to account for time spent away from the radiation exposure area. The shielding and occupancy factor used in this analysis is 0.5 and is taken from Regulatory Guide 1.109 (NRC77).

Table J.10 Soil removal rate constants and radioactive decay constants

Nuclide	Soil Removal Rate Constants (y^{-1})	Radioactive Decay Constants, λ Dn (y^{-1})
U-238	2.58×10^{-4}	1.54×10^{-10}
U-234	2.58×10^{-4}	2.81×10^{-6}
Ra-226	7.74×10^{-3}	4.33×10^{-4}
Rn-222	4.93	6.62×10^{1}
Pb-214	1.94×10^{-4}	1.36×10^{4}
Bi-214	7.63×10^{-2}	1.85×10^{4}
Pb-210	1.94×10^{-4}	3.30×10^{-2}
Po-210	3.26×10^{-3}	1.83×10^{0}

Table J.11 Milk and beef concentration factors

Nuclide	Milk Concentration Factor (Ci/ℓ milk per Ci/d intake)	Beef Concentration Factor (Ci/kg beef per Ci/day intake)
U-238	1.40×10^{-4}	1.60×10^{-6}
U-234	1.40×10^{-4}	1.60×10^{-6}
Ra-226	5.90×10^{-4}	5.00×10^{-4}
Rn-222	2.00×10^{-2}	2.00×10^{-2}
Pb-214	8.70×10^{-5}	9.10×10^{-4}
Bi-214	5.00×10^{-4}	1.70×10^{-2}
Pb-210	9.90×10^{-5}	9.10×10^{-4}
Po-210	1.20×10^{-4}	8.70×10^{-3}

J.25 Milk and Beef Ingestion Rates by Humans and Milk and Beef Cow Drinking Water Rates

The milk ingestion rate by humans is assumed to be 112 ℓ/y which is the value used in AIRDOS-EPA (Mo79). In computing dose equivalents for the beef ingestion pathway, hogs and sheep are lumped into the beef pathway. This simplified the calculations, and it is believed that the assumption is reasonable since cattle account for well over 50 percent of the meat production in both the New Mexico and Wyoming assessment areas (DOA73, DOA79). The meat ingestion rate by humans is assumed to be 85 kg/y, which is the value listed for adults in AIRDOS-EPA (Mo79). This ingestion rate is employed in determining the number of persons who could be fed from meat produced within the assessment areas, as discussed in Section J.14.

The milk cow drinking water intake used in these calculations is 60 ℓ/d; for beef cattle, the value is 50 ℓ/d. Both values are the ones suggested in Regulatory Guide 1.109 (NRC77).

J.26 Radionuclide Concentration Factors for Milk and Beef

The radionuclide concentration factors for milk and beef express the concentration of radionuclides in milk or beef per unit daily intake of radionuclides by cattle drinking water. The values for these parameters are taken from AIRDOS-EPA (Mo79) and are listed in Table J.11.

J.27 Dosimetry Factors

Internal and external dosimetry factors are derived from the RADRISK data library which is being developed by Oak Ridge National Laboratory (Du80). The organs listed are considered to be the more dosimetrically significant organs. Breast dosimetry factors were used for the calculations for muscle since the muscle factors were not listed in RADRISK and since the breast and muscle factors should be similar in magnitude. The dosimetry factors tabulated as "weighted mean" were obtained by summing over organs the product of the organ dosimetry factors and a relative-risk weighting factor for the organ. These dosimetry factors are not the same as total-body dosimetry factors but are an attempt to express an overall dose that has been weighted for risk due to exposing each individual organ. Weighting factors were chosen to have a sum of 1.

For the inhalation pathway, the dosimetry factors incorporate the "Task Group Lung Model" (TGLD66). All nuclides are assumed to be of Class W solubility and an AMAD of 1.0μm is used. Class W solubility is assumed rather than Class Y because it is believed that in order for radioactive compounds to be soluble in mine water they must be in a more soluble chemical form than Class Y compounds. The dosimetry factors used in these assessments are listed in Table J.12.

J.28 Health Effects Conversion Factors

Health effects conversion factors for the internal and external pathways are derived from the RADRISK data library (Du80). Internal health effects conversion factors are needed for both inhalation and ingestion. For these internal pathways, the conversion factors are specific to each radionuclide and express the potential health impact per unit radionuclide intake. External health effects conversion factors are a function of organ but are radionuclide independent. The factors relate potential health impact to external radiation dose equivalent. Separate sets of health effect conversion factors are needed to estimate potential somatic health effects (fatal cancers) and potential genetic effects (genetic defects in the offspring of the exposed persons). The health effects conversion factors for the internal pathways are listed in Table J.13, and those for the external pathways are listed in Table J.14. Additional discussion of the philosophy of health impact determination used to obtain the data in the RADRISK data library is included in Section L.1 of Appendix L.

TABLE J.12
DOSE EQUIVALENT CONVERSION FACTORS

(INHALATION AND INGESTION=REM/CI INTAKE   AIR SUBMERSION=REM/Y PER CI/M**3   GROUND CONTAMINATION=REM/Y PER CI/M**2)

NUCLIDE	PATHWAY	ORGAN											
		ENDOST. CELLS	RED MARROW	LUNG	LIVER	STOMACH WALL	LLI WALL	THYROID	KIDNEY	WEIGHTED MEAN	MUSCLE	OVARIES	TESTES
U-238	INHALATION	1.29E+07	4.54E+05	8.40E+07	6.40E+04	8.11E+03	1.02E+05	6.30E+04	6.63E+06	2.48E+07	6.31E+04	6.00E+04	6.01E+04
	INGESTION	1.15E+07	4.02E+05	4.99E+03	5.30E+04	8.56E+03	1.40E+05	5.58E+04	5.90E+06	3.61E+05	5.59E+04	5.30E+04	5.34E+04
	EXT. AIR SUBMERSION	3.47E+02	3.08E+02	1.26E+02	2.86E-03	1.07E+02	8.18E+01	1.58E+02	9.06E+01	1.83E+02	2.37E+02	9.60E+01	2.62E+02
	EXT. GROUND CONTAM.	2.71E+01	2.32E+01	8.59E+00	2.97E+00	7.26E+00	8.41E+00	7.05E+00	3.04E+00	1.84E+01	3.29E+01	5.32E+00	3.89E+01
U-234	INHALATION	1.58E+07	4.66E+05	9.52E+07	7.04E+04	8.33E+03	8.19E+04	7.04E+04	7.46E+06	2.82E+07	7.04E+04	7.04E+04	7.04E+04
	INGESTION	1.41E+07	4.24E+05	5.53E+03	6.26E+04	9.63E+03	1.52E+05	6.26E+04	6.64E+06	4.19E+05	6.26E+04	6.26E+04	6.26E+04
	EXT. AIR SUBMERSION	1.08E+03	9.80E+02	4.68E+02	3.76E+02	3.72E+02	2.90E+02	6.18E+02	3.75E+02	5.91E+02	6.15E+02	2.96E+02	6.85E+02
	EXT. GROUND CONTAM.	4.82E+01	4.22E+01	1.77E+01	1.00E+01	1.45E+01	1.46E+01	1.85E+01	9.92E+00	3.06E+01	4.71E+01	1.07E+01	5.53E+01
RA-226	INHALATION	2.54E+07	1.46E+06	9.55E+07	5.97E+05	3.91E+03	1.81E+05	6.37E+05	5.98E+05	2.87E+07	6.37E+05	6.38E+05	6.37E+05
	INGESTION	2.26E+07	1.30E+06	1.91E+03	5.32E+05	5.45E+03	3.35E+05	5.67E+05	5.33E+05	8.07E+05	5.68E+05	5.69E+05	5.67E+05
	EXT. AIR SUBMERSION	5.87E+04	5.49E+04	3.37E+04	2.91E+04	2.49E+04	2.09E+04	3.81E+04	2.76E+04	3.65E+04	3.42E+04	2.00E+04	4.68E+04
	EXT. GROUND CONTAM.	1.30E+03	1.21E+03	7.43E+02	6.41E+02	5.49E+02	4.61E+02	8.41E+02	6.09E+02	8.05E+02	7.57E+02	4.41E+02	1.02E+03
RN-222	INHALATION	3.32E+01	5.46E+00	1.03E+03	7.32E+00	4.88E-01	1.43E-02	1.02E+00	4.46E+01	3.03E+02	1.02E+00	1.01E+00	1.00E+00
	INGESTION	3.40E+04	6.00E+03	1.17E+02	7.39E+03	1.48E+04	6.87E+05	4.50E+02	1.40E+04	2.61E+04	1.06E+03	5.62E+03	9.12E+02
	EXT. AIR SUBMERSION	2.59E+03	2.48E+03	2.00E+03	1.85E+03	2.12E+03	1.56E+03	1.77E+03	1.86E+03	2.09E+03	2.14E+03	7.96E+02	2.40E+03
	EXT. GROUND CONTAM.	5.33E+01	5.12E+01	4.12E+01	3.80E+01	4.36E+01	3.21E+01	3.65E+01	3.83E+01	4.30E+01	4.40E+01	1.64E+01	4.94E+01
PB-214	INHALATION	7.37E+03	1.15E+03	9.34E+04	1.49E+03	1.03E+02	3.02E+00	1.55E+02	9.11E+03	2.78E+04	1.56E+02	1.52E+02	1.50E+02
	INGESTION	2.17E+03	3.19E+02	7.70E+00	4.18E+02	3.14E+03	1.03E+02	2.51E+01	1.01E+03	2.79E+02	3.55E+01	6.44E+01	2.70E+01
	EXT. AIR SUBMERSION	1.86E+06	1.76E+06	1.25E+06	1.11E+06	1.11E+06	8.72E+05	1.23E+06	1.09E+06	1.32E+06	1.30E+06	6.14E+05	1.61E+06
	EXT. GROUND CONTAM.	4.02E+04	3.81E+04	2.68E+04	2.39E+04	2.39E+04	1.87E+04	2.66E+04	2.35E+04	2.84E+04	2.81E+04	1.32E+04	3.45E+04
BI-214	INHALATION	5.38E+02	1.35E+02	6.97E+04	8.44E+01	7.17E+01	2.83E+01	7.93E+01	8.42E+03	2.05E+04	8.00E+01	7.69E+01	7.62E+01
	INGESTION	2.37E+02	2.83E+01	7.57E+00	1.63E+01	3.18E+03	2.57E+01	4.17E+00	3.85E+02	1.54E+02	1.05E+01	2.02E+01	4.88E+00
	EXT. AIR SUBMERSION	9.43E+06	8.72E+06	8.28E+06	7.54E+06	7.92E+06	6.81E+06	7.87E+06	7.04E+06	8.33E+06	8.74E+06	6.93E+06	6.74E+06
	EXT. GROUND CONTAM.	1.65E+05	1.52E+05	1.44E+05	1.31E+05	1.38E+05	1.17E+05	1.35E+05	1.23E+05	1.45E+05	1.52E+05	1.17E+05	1.20E+05
PB-210	INHALATION	6.52E+06	3.81E+05	1.08E+07	2.58E+06	1.18E+03	4.56E+04	1.48E+05	2.30E+06	3.58E+06	1.48E+05	1.48E+05	1.48E+05
	INGESTION	5.80E+06	2.91E+05	9.05E+01	2.16E+06	2.04E+02	1.77E+04	8.17E+04	1.00E+06	3.39E+05	8.17E+04	8.18E+04	8.17E+04
	EXT. AIR SUBMERSION	1.32E+04	1.19E+04	4.94E+03	3.93E+03	4.19E+03	2.38E+03	7.34E+03	4.36E+03	6.47E+03	6.29E+03	3.97E+03	6.72E+03
	EXT. GROUND CONTAM.	4.42E+02	3.97E+02	1.66E+02	1.28E+02	1.46E+02	8.07E+01	2.42E+02	1.42E+02	2.22E+02	2.28E+02	1.32E+02	2.62E+02
PO-210	INHALATION	3.78E+05	8.20E+05	7.84E+07	2.52E+06	2.22E+03	8.84E+04	8.10E+05	1.46E+07	2.37E+07	8.10E+05	8.10E+05	8.10E+05
	INGESTION	2.44E+05	5.32E+05	1.15E-02	1.63E+06	4.52E+03	1.80E+05	5.26E+05	9.44E+06	5.67E+05	5.26E+05	5.26E+05	5.26E+05
	EXT. AIR SUBMERSION	5.26E+01	4.87E+01	4.33E+01	3.93E+01	4.11E+01	3.08E+01	3.52E+01	4.25E+01	4.39E+01	4.62E+01	2.38E+01	4.49E+01
	EXT. GROUND CONTAM.	1.02E+00	9.45E-01	8.40E-01	7.62E-01	7.97E-01	5.97E-01	6.82E-01	8.24E-01	8.51E-01	8.95E-01	4.62E-01	8.70E-01

Table J.13 Health effects conversion factors for internal pathways

Nuclide	Somatic (fatal cancers/Ci intake)		Genetic (genetic defects/Ci intake)	
	Inhalation	Ingestion	Inhalation	Ingestion
U-238	3.67×10^{3}	4.79×10^{1}	8.07×10^{1}	7.20×10^{1}
U-234	4.14×10^{3}	5.38×10^{1}	9.57×10^{1}	8.55×10^{1}
Ra-226	4.21×10^{3}	1.01×10^{2}	8.57×10^{2}	7.65×10^{2}
Rn-222	4.51×10^{-2}	5.64	1.49×10^{-3}	1.49
Pb-214	4.15	6.47×10^{-2}	2.30×10^{-1}	4.24×10^{-2}
Bi-214	3.04	3.34×10^{-2}	1.13×10^{-1}	7.81×10^{-3}
Pb-210	5.31×10^{2}	3.94×10^{1}	1.69×10^{2}	7.82×10^{1}
Po-210	3.50×10^{3}	9.67×10^{1}	1.21×10^{3}	7.84×10^{2}

Table J.14 Health effects conversion factors for external pathways

Organ	Somatic (fatal cancers/rem)	Genetic (genetic defects/rem)
Endosteal	4.35×10^{-6}	0
Red Marrow	4.59×10^{-5}	0
Lung	8.59×10^{-5}	0
Liver	2.20×10^{-5}	0
Stomach Wall	1.23×10^{-5}	0
LLI Wall	9.81×10^{-6}	0
Thyroid	1.20×10^{-5}	0
Kidney	4.90×10^{-6}	0
Muscle	9.31×10^{-5}	0
Ovaries	2.46×10^{-6}	3.00×10^{-4}
Testes	2.46×10^{-6}	3.00×10^{-4}

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